XII. *A Method of examining refractive and dispersive Powers, by prismatic Reflection. By* William Hyde Wollaston, *M.D. F.R.S.*

Read June 24, 1802.

In examining the power with which various substances refract and disperse light, I have for some time past employed a method unnoticed by writers on optical subjects; and, as it is not only convenient in common cases of refraction, but also capable of affording results not attainable by other means, I have been induced to draw up a short account of the method itself, and of the most remarkable instances of its application.

This method was suggested by a consideration of Sir Isaac Newton's prismatic eye-glass, the principle of which depends on the reflection of light at the inner surface of a dense refracting medium.

Since the range of inclination within which total reflection takes place, depends not only on the density of the reflecting prism, but also on the rarity of the medium adjacent to it, the extent of that range varies with the difference of the densities of the two media. When, therefore, the refractive power of one medium is known, that of any rarer medium may be learned, by examining at what angle a ray of light will be reflected from it.

For instance, when any object is laid under a prism of flint-glass, with air alone interposed, the internal angle of incidence at which the visual ray begins to be totally reflected, and at which

the object ceases to be seen by refraction, is about 39° 10′; but, when the object has been dipped in water, and brought into contact with the glass, it continues visible, by means of the higher refractive power of the water, as far as $57\frac{1}{2}°$ of incidence. When any kind of oil, or any resinous cement, is interposed, this angle is still greater, according to the refractive power of the medium employed; and, by cements that refract more strongly than the glass, the object may be seen through the prism, at whatever angle of incidence it is viewed.

In examining the refractive powers of fluids, or of fusible substances, the requisite contact is easily obtained; but, with solids, which can in few instances be made to touch to any great extent, this cannot be effected without the interposition of some fluid, or cement, of higher refractive power than the medium under examination. Since the surfaces of a stratum so interposed are parallel, it will not effect the total deviation of a ray passing through it, and may therefore be employed without risk of any error in consequence.

Thus, resin, or oil of sassafras, interposed between plate glass and any other prism, will not alter the result.

If, on the same prism, a piece of selenite and another of plate-glass be cemented near each other, their powers may be compared with the same accuracy as if they were both in absolute contact with it.

For such a mere comparison of any two bodies, a common triangular prism is best adapted; but, for the purpose of actual measurement of refractive powers, I have preferred the use of a square prism, because, with a very simple apparatus, it shows the sine of refractive power sought, without the need of any calculation.

Let A, Fig. 1, Plate XIV. be a square or rectangular prism, to which any substance is applied at *b*, and let any ray of light parallel to *cb* be refracted through the prism, in the direction *bde*.

Then, if *ef* and *ed* be taken proportional to the sines that represent the refractive powers of the prism and of air, *fg*, which is intercepted between *f* and the perpendicular *eg*, will be the corresponding sine to represent the refractive power of the medium *b*. For, since *edg* (opposite to *ef*) is the angle of refraction, *efg* (opposite to *ed*) must be equal to the angle of incidence *bdh*; and *ef* : *fg* : : *bd* : *dh* : : sine of *cbi* : sine of *hbd*.

All therefore that is requisite for determining the refractive power of *b*, is to find means of measuring the line *fg*. On this principle, the instrument in the annexed sketch (Fig. 2.) is constructed. On a board *ab* is fixed a piece of flat deal *cd*, to which, by a hinge at *d*, is jointed a second piece *de*, 10 inches long, carrying two plane sights at its extremities. At *e* is a second hinge, connecting *ef*, 15,83 inches long; and a third at the other extremity of *ef*, by which *fg* is connected with it. At *i* also is a hinge, uniting the radius *ig* to the middle of *ef*; and then, since *g* moves in a semicircle *egf*, a line joining *e* and *g* would be perpendicular to *fg*.

The piece *cd* has a cavity in the middle of it, so that, when any substance is applied to the middle of the prism P, it may continue to rest horizontally on its extremities. When *ed* has been so elevated that the yellow rays in the fringe of colours (observable where perfect reflection terminates) are seen through the sights, the point *g*, by means of a vernier which it carries, shows by inspection the length of the sine of refraction sought.

The advantages which this method possesses above the usual mode of examining refractive powers, are greater than they may at first sight appear. The usual practice has been, to form two surfaces of the substance under examination, so inclined to each other that the deviation occasioned by them might be measured. The inclination of these surfaces to each other must also be known; and thence the refractive power might be computed. But, in the method here proposed, it is sufficient to have only one surface, and the result is obtained at once, without computation.

The facility of determining refractive powers, is consequently such as to render this property of bodies a very convenient test in many philosophical inquiries. For discovering the purity of essential oils, such an examination may be of considerable utility, on account of the smallness of the quantity requisite for trial. In oil of cloves, for instance, I have met with a wide difference. The refractive power of genuine oil of cloves, is as high as 1,535; but I have also purchased oil by this name, which did not exceed 1,498, and which had probably been adulterated by some less refractive oil.

For such purposes, the refractive power of opaque substances may often be deserving of inquiry, which could not be learned by any means at present in use. For, in the usual mode, a certain degree of transparency is absolutely necessary; but, for trial by contact, the most perfect opacity does not occasion the least impediment.

Among other instances in which I have taken advantage of this circumstance, I may mention a substance that had been found in one of the islands of the North Pacific Ocean, which, to all outward appearance and by various trials, seemed to be perfect bees-wax, although it is supposed that there are no bees in the

island from which it was brought. On placing it by the side of a piece of bees-wax, in contact with a prism, the perfect equality of their refractive powers afforded a strong confirmation of the opinion before formed of their identity.

For the examination also of media of which the refractive density is not uniform, the general method of trial by deviation wholly fails; on the contrary, by placing a varied medium in contact with a prism, all its gradations of density, from greatest to least, become at once the object of mere inspection. An instance of this may very readily be seen with a piece of gum, the surface of which has been moistened for a few minutes; when, by close application to a prism, a refractive power may be discerned, varying from that of the water on the surface, 1,336, to nearly 1,51, the refractive power of gum arabic.

I should not so much insist on this advantage, were it not for the opportunity hereby afforded of examining the crystalline lens of the eye, which is now known to be generally more dense in the centre than at its surface.

Mr. HAUKSBEE, who was not aware of this difference, has estimated the refractive power of the crystalline lens, by forming it into a wedge by plates of glass, somewhat higher than I find it to be; but, with his accustomed accuracy, he remarked the apparent enlargement of an object, occasioned by the variations of its density, which he was unable to explain.

In the table that follows, I have set down, not only the limits of refractive power in a crystalline lens of an ox, ascertained by trial, but also an average, computed from the refractive density of a dried crystalline of an ox, of which the weight had been first taken in the recent state, and the quantity of water lost by drying also measured.

The table exhibits a series of substances, arranged according to their refractive powers. That of the diamond is copied from Sir ISAAC NEWTON; of other bodies to which (on account of their being more dense than glass) the machine for measurement would not apply, the refractive powers have been found by other means, for the sake of furnishing a more continued series of subjects for comparative experiments. The rest have been compared by this method; and their power, when expressed in numbers, actually measured.

TABLE I.

Diamond - -	2,44	Horn	—
Plumbago -	——	Phosphorus - -	1,579
Native sulphur (double)	2,04	Mica	—
Glass, consisting of lead 6 and sand 1 -	1,987	Opium	—
Glass of antimony -	1,98	Amber - -	1,547
Jargon - -	1,95	Rock crystal (double)	1,547
Spinelle ruby -	1,812	*Old plate glass* -	1,545
Arsenic - -	1,811	Colophony - -	1,543
Muriate of antimony,	variable	Box-wood	—
White sapphire -	1,768	Bees-wax - -	1,542
Gum dragon -	—	Oil of sassafras -	1,536
Iceland spar, strongest	1,657	Red sealing-wax	—
Sulphate of barytes (double) -	1,646	Spermaceti, cold	—
Balsam of Tolu -	1,60	Sugar, after fusion	—
Guaiacum - -	1,596	Arseniate of potash	—
Benzoin -	—	Mastic	—
Flint glass - -	1,586	Elemi	—
Ditto - -	1,583	White wax (cold)	—
		Oil of cloves - -	1,535
		Copal - -	1,535

Anime - -	1,535
Radcliffe crown glass -	1,533
Pitch	—
Centre of crystalline of fish, and dry crystalline of an ox -	1,530
Canada balsam -	1,528
Crown glass, common	1,525
Selenite - -	1,525
Caoutchouc -	1,524
Gum lac	—
Dutch plate glass -	1,517
Human cuticle	—
Gum arabic - -	1,514
Balsam of capivi -	1,507
Oil of amber -	1,505
English plate glass -	1,504
French plate glass -	1,500
Oil of nutmeg -	1,497
Sulphate of potash -	1,495
Tallow, cold - -	1,49
Iceland spar, weakest	1,488
Camphor - -	1,487
Linseed oil - -	1,485
Butter, cold - -	1,480
Essence of lemon -	1,476
Oil of turpentine, common - -	1,476
——— rectified	1,470
Oil of almonds	—
—— olives - -	1,469
—— peppermint -	1,468
—— lavender -	1,467
Tallow, *melted* -	1,460
Alum - - -	1,457
Spermaceti, *melted* -	1,446
Crystalline lens of an ox	1,447
to -	1,380
Computed average of ditto - -	1,430
Sulphuric acid -	1,435
Fluor spar - -	1,433
Nitric acid (sp. gr. 1,48)	1,410
Alcohol - -	1,37
White of an egg -	1,36
Æther - -	1,358
Vitreous humour of an eye - -	1,336
Water - -	1,336
Atmospheric air (HAUKSBEE) -	1,00032

ON THE DISPERSION OF LIGHT.

The method above described for investigating refractive powers, may also be employed with similar advantage for inquiries into the dispersion of light by different bodies, and the consequences that result from their combined action.

When a glass prism is placed in contact with water, and brought near the eye, in such a position that it reflects the light from a window, the extent of perfect reflection is seen to be bounded by a fringe of the prismatic colours, in the order of their refrangibility.* The violet rays, being in this case the most refrangible, appear strongest and lowest, on account of the less obliquity that is requisite for their reflection.

But it may happen that two media, which refract unequally at the same incidence, may disperse equally at that incidence. Under these circumstances, a pencil of rays passing from one of such media into the other, will be refracted, without dispersion of its colours. The boundary of prismatic reflection would then be found a well defined line, free from colour, if the surface at which the reflected light emerges from the prism were at right angles to its course.

When the disparity of the dispersive powers of the media is still greater, it may also happen, that the usual order of prismatic colours will be reversed; and then the red will appear strongest and lowest in the fringe, unless the colours so produced are counteracted by refraction at their emergence from the prism.

An instance in which the colours are so reversed, may be seen by application of oil of sassafras to a prism of flint glass.

* NEWTON'S Optics. Book i. part 2. Exp. 16.

So high is the dispersive power of this oil, that, in refractions from flint glass into it, the red rays are refracted more than the violet.

It must be observed that, in this experiment, when the angle of reflection within a triangular prism exceeds 60°, the angle of emergence is such as would alone occasion the red rays to appear lowermost; but, when the glass used is rectangular, the refraction at emergence has an opposite effect; any reversion of colour will therefore be in some degree corrected, and may not be seen, unless the dispersive power of the medium in contact much exceeds that of the glass.

A case of refraction with an inverted order of colours, has been observed by Dr. BLAIR,* in a compound object-glass, where crown-glass was in contact with oil of turpentine. From trials with lenses, he likewise inferred, that several other fluids have the same effect, when applied to that glass.

With this glass, and also with plate-glass, I have tried oil of turpentine, and many other fluids that afford a similar reversion of colours, as linseed-oil, olive-oil, the essential oils of bergamot, lemon, lavender, pennyroyal, and peppermint, strong nitric acid, and many artificial compounds that I shall presently have occasion to mention.

The dispersive power of fluor spar is the least of any substance yet examined; so that, although its refractive power is also remarkably low, (considering its great specific gravity,) a prism of fluor, in contact with water or alcohol, shows the prismatic colours to be refracted in an inverted order.

With heavy spar, the instances of reversion are very numerous, as its dispersive power is low, and is accompanied with

* Edinb. Trans. Vol. III.

great refractive density. In the refractions from this spar into flint glass, and into all oils or resins, I believe, without exception, the colours are seen reversed.

Rock crystal likewise disperses so little, that it exhibits the colours reversed, when it is in contact with many substances of less refractive power than itself. I have tried it with Dutch plate-glass, with Canada balsam and balsam of capivi, with many oils essential and expressed, and have found the colours in all these cases reversed.

By solutions of metallic salts, a great variety of such appearances may be produced. Most of these compounds have a highly dispersive power; and many of them may be rendered sufficiently dense to occasion reversion, even when applied to flint-glass. In a more dilute state, they may be used with crown-glass, or plate-glass, to produce the same effect. And since, when further diluted by a less dispersive medium, they will also present an appearance of colourless refraction, we may, by examining the degree of dilution necessary for that purpose, compare the dispersive powers of any ingredients contained in them, and may gradually extend our knowledge of this property to the elements of any bodies, however compounded.

As a specimen of the method, I have in this way compared a few solutions of metals, and of other substances, that were each diluted till the limit of reflection appeared void of colour, when they were in contact with a rectangular piece of plate-glass; and, in the table which follows, I have expressed their refractive powers in that state of dilution, as nearly as the eye can discern the disappearance of colour.

TABLE II.

	In Water.	In Alcohol.
Nitro-muriate of gold - -	1,364	1,390
Nitro-muriate of platina - -	1,370	
Nitrate of iron - - - -	1,375	
Sulphuret of potash - - -	1,375	
Red muriate of iron - - -	1,385	
Nitrate of magnesia		
Nitric acid - - - -	1,395	
Nitrate of jargon		
Balsam of Tolu - - - -	—	1,400
Acetite of litharge (extract of lead) -	1,400	
Nitrate of silver		
Nitrate of copper		
Oil of sassafras - - -	—	1,405
Muriate of antimony - - -	—	1,410
Nitrate of lime - - -	1,410	1,422
Nitrate of zinc		
Green muriate of iron - - -	1,415	
Muriate of magnesia - - -	1,416	
——— of lime - - - -	1,425	1,440
——— of zinc - - -	1,425	
Essence of lemon - - - -	—	1,430
Balsam of capivi - - - -	—	1,440

It may here be seen, that several of the metals increase the dispersive powers of nitric and muriatic acids, and consequently exceed them in that respect. Of all these substances that I have yet tried, gold and platina are the most dispersive. The least dispersive of the metals is zinc.

The earths also are found to possess this property in very different degrees: that of the jargon and magnesia differ but little from nitric acid in dispersive power; but siliceous earth, on the contrary, is inferior to water.

By comparing the salts formed with the nitric and muriatic acids, it appeared probable that the former had the higher dispersive power; but a more direct comparison could not be made by means of the rectangular piece of plate-glass, as muriatic acid could not be rendered sufficiently dense for such a trial; I therefore made use of a triangular prism of crown-glass, which is in itself less dispersive than any plate-glass, and, from the relative position of its surfaces, occasioned less correction of the colours. With this prism, I found that strong muriatic acid (having a refractive power 1,394) exhibited the colours reversed; and that, when it was diluted till the limit of reflection appeared void of colour, its refractive power was reduced to 1,382. But the dispersive power of nitric acid, when tried by the same prism, proved to be greater; for this acid required to be diluted till its refractive power did not exceed 1,375, before the colour was wholly destroyed.

In the table it may be observed, that the red and green muriates of iron, though consisting of the same metal and acid, differ very much in dispersive power; and, consequently, that some caution will be necessary, in attempting to compare the different metals with each other by means of the salts containing them, as any difference observed may be owing in part to a difference in the quantity of acid to which they are united, and in part to their different proportion of oxygen.

A striking instance of the latter is manifest, from a comparison of sulphur with the sulphuric acid; for, while the former

appears to exceed the metallic oxides in dispersive power, the latter is inferior even to water.

As I have likewise, at various times, made many experiments on dispersion by means of wedges, in a manner nearly similar to that employed by Mr. Dollond, Dr. Blair, and others, I have endeavoured to reduce the several substances thus examined to one table; but, as the limits of colour are in few instances sufficiently well defined for accurate mensuration, I have not attempted to add any numerical estimate of their powers, but have merely ascertained the order in which they succeed each other; and, in the following table, have arranged them according to the excess of their effect on violet above red light, at a given angle of deviation.

Table III.

Order of dispersive Powers.	Refr. Power.	Order of dispersive Powers.	Refr. Power.
Sulphur - -	2,04	Amber - -	1,547
Glass of lead ($\frac{1}{7}$ sand)	1,987	Diamond - -	2,44
Balsam of Tolu -	1,60	Alum - - -	1,457
Oil of sassafras - -	1,536	Plate-glass, Dutch -	1,517
Muriate of antimony		Ditto, English -	1,504
Guaiacum - -	1,596	Crown glass - -	1,533
Oil of cloves - -	1,535	Ruby (spinelle) -	1,812
Flint-glass - -	1,586	Water - - -	1,336
Colophony - -	1,543	Sulphuric acid -	1,435
Canada balsam -	1,528	Alcohol - - -	1,37
Oil of amber - -	1,505	Sulphate of barytes -	1,646
Jargon - -	1,95	Selenite - -	1,525
Oil of turpentine -	1,47	Rock crystal - -	1,547
Copal - - -	1,535	Sulphate of potash -	1,495
Balsam of capivi -	1,507	White sapphire -	1,768
Anime - -	1,535	Fluor spar - -	1,433
Iceland spar - -	1,657		

By comparison of this table with the order of refractive powers, as contained in the first table, it will be seen how little correspondence there is between them; and, accordingly, how numerous are the combinations by means of which a pencil of rays that passes through two media, may be made to deviate without dispersion of its colours.

I cannot conclude these observations on dispersion, without remarking that the colours into which a beam of white light is separable by refraction, appear to me to be neither 7, as they usually are seen in the rainbow, nor reducible by any means (that I can find) to 3, as some persons have conceived; but that, by employing a very narrow pencil of light, 4 primary divisions of the prismatic spectrum may be seen, with a degree of distinctness that, I believe, has not been described nor observed before.

If a beam of day-light be admitted into a dark room by a crevice $\frac{1}{20}$ of an inch broad, and received by the eye at the distance of 10 or 12 feet, through a prism of flint-glass, *free from veins*, held near the eye, the beam is seen to be separated into the four following colours only, red, yellowish green, blue, and violet; in the proportions represented in Fig. 3.

The line A that bounds the red side of the spectrum is somewhat confused, which seems in part owing to want of power in the eye to converge red light. The line B, between red and green, in a certain position of the prism, is perfectly distinct; so also are D and E, the two limits of violet. But C, the limit of green and blue, is not so clearly marked as the rest; and there are also, on each side of this limit, other distinct dark lines, *f* and *g*, either of which, in an imperfect experiment, might be mistaken for the boundary of these colours.

The position of the prism in which the colours are most clearly divided, is when the incident light makes about equal angles with two of its sides. I then found that the spaces AB, BC, CD, DE, occupied by them, were nearly as the numbers 16, 23, 36, 25.

Since the proportions of these colours to each other have been supposed by Dr. Blair to vary according to the medium by which they are produced, I have compared with this appearance, the coloured images caused by prismatic vessels containing substances supposed by him to differ most in this respect, such as strong but colourless nitric acid, rectified oil of turpentine, very pale oil of sassafras, and Canada balsam, also nearly colourless. With each of these, I have found the same arrangement of these 4 colours, and, in similar positions of the prisms, as nearly as I could judge, the same proportions of them.

But, when the inclination of any prism is altered so as to increase the dispersion of the colours, the proportions of them to each other are then also changed, so that the spaces AC and CE, instead of being as before 39 and 61, may be found altered as far as 42 and 58.*

* Although what I have above described comprises the whole of the prismatic spectrum that can be rendered visible, there also pass on each side of it other rays, whereof the eye is not sensible. From Dr. Herschel's experiments (Phil. Trans. for 1800) we learn, that on one side there are invisible rays occasioning heat, that are less refrangible than red light; and on the other I have myself observed, (and the same remark has been made by Mr. Ritter,) that there are likewise invisible rays of another kind, that are more refracted than the violet. It is by their chemical effects alone that the existence of these can be discovered; and, by far the most delicate test of their presence is the white muriate of silver.

To Scheele, among many valuable discoveries, we are indebted for having first duly distinguished between radiant heat and light; (*Traité de l'Air et du Feu*, § 56, 57;) and to him also we owe the observation, that when muriate of silver is exposed

By candle-light, a different set of appearances may be distinguished. When a very narrow line of the blue light at the lower part of the flame is examined alone, in the same manner, through a prism, the spectrum, instead of appearing a series of lights of different hues contiguous, may be seen divided into 5 images, at a distance from each other. The 1st is broad red, terminated by a bright line of yellow; the 2d and 3d are both green; the 4th and 5th are blue, the last of which appears to correspond with the division of blue and violet in the solar spectrum, or the line D of Fig. 3.

When the object viewed is a blue line of electric light, I have found the spectrum to be also separated into several images; but the phenomena are somewhat different from the preceding. It is, however, needless to describe minutely, appearances which vary according to the brilliancy of the light, and which I cannot undertake to explain.

to the common prismatic spectrum, it is blackened more in the violet than in any other kind of light. (§ 66.) In repeating this experiment, I found that the blackness extended not only through the space occupied by the violet, but to an equal degree, and to about an equal distance, beyond the visible spectrum; and that, by narrowing the pencil of light received on the prism, the discoloration may be made to fall almost entirely beyond the violet.

It would appear therefore, that this and other effects usually attributed to light, are not in fact owing to any of the rays usually perceived, but to invisible rays that accompany them; and that, if we include two kinds that are invisible, we may distinguish, upon the whole, six species of rays into which a sun-beam is divisible by refraction.

Fig. 1.

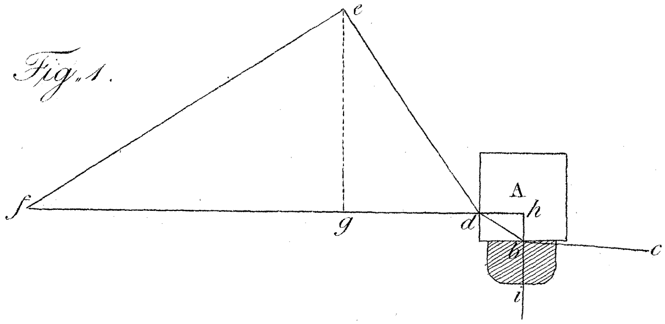


Fig. 2.

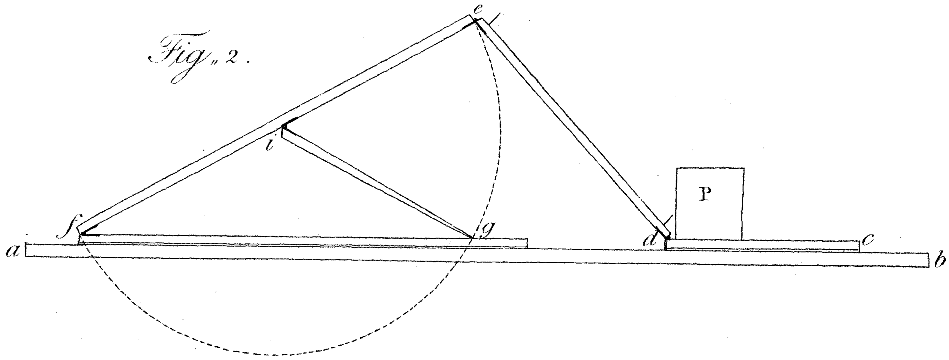
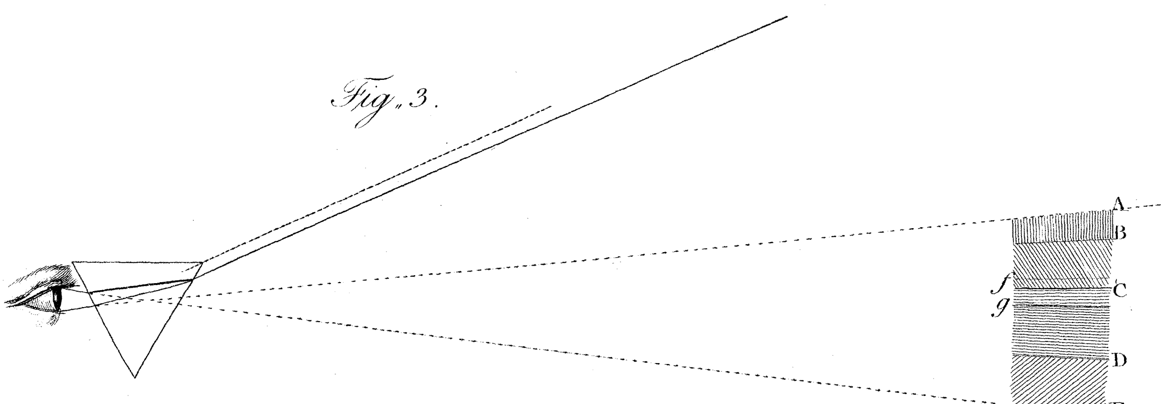


Fig. 3.



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